Components for an Incident Management Simulation and Gaming Framework and Related Developments

Sanjay Jain

Department of Decision Sciences, School of Business

George Washington University

2201 G Street NW, # 415

Washington, DC 20052, USA

jain@gwu.edu

Charles R. McLean

National Institute of Standards and Technology

Gaithersburg, MD, USA

The nation's emergency responders need to work in a coordinated, well-planned manner to best mitigate the impact of an emergency incident. They need to be trained and be ready to act in view of the increased security threat. The training has been traditionally provided using live exercises at a great expense. Simulation and gaming systems could provide a wider range of training at a much lower cost. Integrated gaming and simulation systems should be used for training of decision makers and responders on the same scenarios preparing them to work together as a team.

A large number of simulation and gaming tools are needed to address the huge number of scenarios that can be of interest for incident management. An efficient approach will be to develop a library of interoperable component models that can be assembled together in different combinations to represent a range of scenarios. Standard specifications of the component models are needed to spur the development. The specifications should allow for alternate competing implementations. This paper presents a conceptual architecture that partitions the incident management simulation and gaming solution space into standard components. Recent literature is surveyed to identify related models and/or simulators where available for each defined component. The suggested components and the survey lay some preliminary groundwork in developing a holistic model of the incident response domain.

Keywords: modeling, simulation, gaming, component, architecture, incident management, emergency response, integration.

1. Motivation

There is a growing need for improved management of both man-made and natural incidents. The man-made disaster risk has increased due to a rise in possibility of terrorist attacks against the United States. Effective incident management through all its phases, that is, prevention, preparedness, response, recovery and mitigation, presents a number of challenges to the responsible agencies. One major challenge is the lack of opportunities to train the emergency responders and the decision makers in dealing with the emergencies. An on the job training approach is not useful given the thankfully infrequent occurrences of such events. The responsible agencies have tried to meet the need through organization of live exercises, but such events are hard to organize and expensive.

Modeling, simulation, and gaming techniques can help address many of the challenges brought forth by the need for improved incident management. Simulation and gaming can be used together such that simulations maintain the technical correctness of the scenario while gaming clients allow the interaction with the trainees. It may be noted that in the context of incident management the term simulation is often used to refer to live exercises. However, this paper limits the discussion to computer based simulations only.

A recent survey [1] indicates that a number of modeling and simulation (M&S) applications for analyzing various disaster events exist. These need to be brought together for studying the impact of disaster events as a whole. The dispersion of a radioactive plume released by terrorists needs to be predicted, the traffic routes used to evacuate the affected areas need to be planned, the demands placed on the hospital resources in the area need to be defined, etc. The individual simulation models such as those for studying the radiological release need to be integrated with those analyzing the traffic movement through the highways and arteries of the affected area, and with those analyzing the resource constraints of hospital systems among others.

To provide the experience of the same scenarios across all levels of an emergency response team requires execution of large-scale live exercises such as those conducted under TOPOFF (Top Officials) series. These large-scale exercises are hard to organize since they require coordination across a large number of agencies across multiple levels of hierarchy. With the large number of resources devoted to such exercises, each exercise cycle costs tens of millions of dollars. TOPOFF 3 series conducted in April 2005 had a budget of $16 million [2]. And, even with all the effort and expenses they are able to expose the responders, emergency managers and government officials to a limited set of scenarios. The creations of emergency events are limited in realism to avoid risk.

The limitations of live exercises can be overcome to a large extent through use of integrated gaming and simulation models that allow emergency response personnel across multiple levels in multiple agencies to get exposed to the same set of scenarios. Use of integrated gaming and simulation over a distributed network can allow people to participate from different locations and thus provide some flexibility in scheduling the resources. Most importantly, use of simulation will allow providing the responders with experience of a wide range of response scenarios and thus significantly improve the emergency preparedness.

This paper proposes a conceptual architecture for integrated gaming and simulation for incident management training. Relevant reported frameworks and architectures for modeling and simulation are reviewed. The proposed overall approach for integrated gaming and simulation tools for incident management training is described. The conceptual architecture is presented and its major simulation components discussed. Examples of relevant available models and simulators from the recent literature are identified for each simulation component. Together, the suggested components and the survey lay some preliminary groundwork in developing a holistic model of the incident response domain. The gaming components are discussed only briefly in this paper to maintain focus. Similarly, the technical aspects of the architecture are identified but not addressed in detail. The paper concludes with discussion of further research for achieving the vision of the integrated gaming and simulation for incident management training.

2. Background

The applicability of modeling and simulation to different phases of incident management has been recognized for decades (see for example [3]). However, the idea of integrating the M&S tools for a more comprehensive modeling of the scenario is more recent. In this section, a few of the efforts for integration of M&S tools for incident management are reviewed.

A number of simulation tools have to be integrated to address multiple aspects of a single disaster event as described in section 1. The need for such integration in the incident management context has been recognized as evident by the urban security project at Los Alamos National Labs that integrated plume simulation and traffic simulation to compute exposures to the cars traveling through the plume [4]. The Simulation Object Framework for Infrastructure Analysis (SOFIA) project at Los Alamos National Laboratory developed a high-quality, flexible, and extensible actor-based software framework for the modeling, simulation, and analysis of interdependent infrastructures [5].

A number of research efforts have been targeted at integration of simulation models outside the context of incident management. In particular, Department of Defense has spent a large effort in developing war gaming capabilities that integrate a number of simulation models and humans-in-the-loop. The United States (U.S.) Department of Defense (DoD) sponsored research in this area started in the late 1980's with Simulation Networking (SIMNET) project for real-time battlefield simulations of tanks in a virtual training environment. Recently one thread of the work is evolving into the Standard Simulation Architecture, designed as a combination of the High Level Architecture (HLA) and the Synchronous Parallel Environment for Emulation and Discrete-Event Simulation (SPEEDES) developed in the mid to late 1990's [6]. In another effort, Model Driven Architecture (MDA) has been proposed for bringing communication driven ideas of HLA together with conceptual driven idea of Discrete Event Systems Specification (DEVS) to allow heterogeneous solutions and migration to alternatives [7] . Overall, the focus of the DoD developments has been on war gaming involving a number of human decision-makers and actors. The associated research should prove to be very useful for integrated simulations for incident management, particularly for training applications.

Simulation applications for homeland security can get a jump start through adaptation of DoD integrated simulations, in particular, for larger jurisdictions with sufficient funding availability. United States Joint Forces Command is carrying out a leading effort in this direction. The Joint Theatre Level Simulation (JTLS) and Joint

Conflict and Tactical Simulation (JCATS) have been integrated for multi-resolution modeling for training of emergency management staff [8]. The integrated system was used successfully for the Determined Promise 2004 homeland security exercise involving a large number of emergency response personnel across multiple locations.

The integration of simulation models requires that the data is translated from one model to another model in the right context. Typically, human analysts have to spend some time ensuring that the translation of data is consistent based on the semantic understanding. Translation using syntactic grammar can be more efficient but not always possible. An agent-based architecture has been developed that uses object-oriented modeling techniques to encapsulate and organize the syntactic information while the semantic information of the objects is examined for data integration purposes [9]. The proposed architecture can provide value for interoperability of incident management simulations.

The Dynamic Information Architecture System (DIAS) has been developed at Argonne National Laboratory as an object-oriented simulation system that provides an integrating framework for new and legacy applications and can adapt to different contexts [10]. The system has been used both for U.S. Department of Defense applications and civilian applications. It is frame-based and uses the concept of entity objects as analogs to the real world entities being studied. It uses an extensive library of entity objects that can be used in modeling environmental, transportation, and command and control applications. The requirements for building the library of objects may require a large effort for implementation of the system in an incident management context.

HLA has been used for integrating distributed simulation models in the manufacturing domain. A neutral reference architecture was developed for integrating distributed manufacturing simulation systems with each other, with other manufacturing software applications, and with manufacturing data repositories [11]. The need for standardization of interfaces was highlighted. Experience from this past research may be useful in the development proposed here.

This brief review of related research indicates the feasibility of developing an architecture for M&S of incident management and at the same time indicates a need for standardization of interfaces and semantic and syntactic representations. The next section presents the proposed approach based on standard components for incident management gaming and simulation.

3. Proposed Approach

A wide range of simulation and gaming tools will be required to meet the need for incident management training. Development of simulation and gaming tools requires high level of expertise and effort. Use of simulation and gaming tools may not be cost effective if monolithic tools are built for specific emergency scenarios. Indeed, the use of distributed simulation models may not be cost effective either if the models are developed for specific locations and scenarios. The approach will be cost effective if the cost of development can be spread over a number of training scenarios. This can be achieved through development of reusable interoperable data-driven component models that can be assembled in selected combinations to represent different scenarios.

The proposed approach requires the definitions of standard components, information models and data interfaces. It will also require availability of relevant data for incident management simulation based on standards. These are all challenging tasks, however, once accomplished they will lead to an environment with cost effective incident management training and ultimately to saving life and property. Currently the large live exercises are limited to those funded directly by Department of Homeland Security or by larger jurisdictions. Cost effective approaches based on simulation and gaming will allow smaller jurisdictions to train their emergency managers and first responders.

The standard component definitions will allow independent research and development organizations and software vendors to develop competing solutions. They may also modify legacy applications to meet the standard definitions. The free market forces will be applicable and bring further cost benefits for the potential user community.

Initial steps to achieve the above vision include organization of the application and solution space. A framework for M&S for incident management is presented in the next section to define the scope of application of M&S tools and to identify training as part of a continuum of applications through the incident management life cycle. A conceptual architecture is developed after that to partition the solution space in to standard components.

4. Framework for Incident management

Jain and McLean [12] define an integrated framework to enable an organized approach to the use of M&S for incident management through partitioning of the associated application space. The primary users of such a framework would be developers of M&S tools as they would gain from an organized approach to the incident management area. The framework identifies the scope of the incident management area, provides a scheme to map the current tools and determine the gaps, and helps identify the interfaces that the tools may have to other tools. It would thus help capture the interoperability requirements for the M&S tools. Although the framework has been designed to help guide the M&S efforts, it may be seen that it provides a general scheme for organizing the incident management area. The framework is reproduced here and described briefly to provide the application context for the proposed architecture.

The framework for incident management is designed to be three dimensional for ease of understanding. The three major dimensions are incident, domain and life-cycle phase.

An incident is defined as "an occurrence or event, natural or human-caused, that requires an emergency response to protect life or property" [13]. The kind of incident will have a large influence on the kind of M&S capabilities that need to be brought together for response and its management. For example, a building explosion and fire event requires capabilities for modeling the impact of explosion and fire on the building structure and its occupants, while a hazardous release in the atmosphere requires capabilities to model the dispersion of the release in the atmosphere. Admittedly there are some capabilities that are required for a number of scenarios. These include capabilities such as traffic simulation and information flow simulation. Also, man-made and natural incidents may have similar impact. For example, forest fires can be initiated by intentional or unintentional actions of people or by natural causes.

A domain is defined as a group of entities that have similar characteristics with respect to incident management considerations. The incident may have an impact across different domains including civilian population, critical infrastructure, and environment. The response to and management of the incident may involve multiple domains including government agencies and private sector. Entities within domains may both suffer the impact of incidents and may be involved in response. The domains may be modeled at a level of detail appropriate to the objective of the study.

Incident management includes five major life-cycle phases – prevention, preparedness, response, recovery, and mitigation for emergency and disaster incidents [13]. The capabilities of the needed M&S tools may differ based on the incident management lifecycle phase they are designed for.

Figure 1 shows the concept of Framework for Incident Management (FIM). The three major dimensions described above form the three axes of the cube that is used to represent the incident management area. Each cell in the cube defines the management and/or impact of an incident type or a specific incident on a particular domain and the associated applications required in the phase defined along the lifecycle dimension. The cells will also include the modeling of results of actions by the entities within the domains. The location of the cell along the lifecycle phase dimension classifies the need for the affected domains.

The Framework for Incident Management also defines the framework for M&S as it defines the needs that M&S applications should satisfy. Each cell of the FIM defines needs that M&S tools can fill or support. For example, incident management may need to address the training requirements for government agencies for a fire disaster event in preparedness lifecycle phase. M&S applications can provide models that train people for various aspects of dealing with a fire emergency, such as determining the escape route, determining the means to put out the fire at individual firefighter level and at the fire company level. The framework thus captures the needs for M&S applications for incident management.

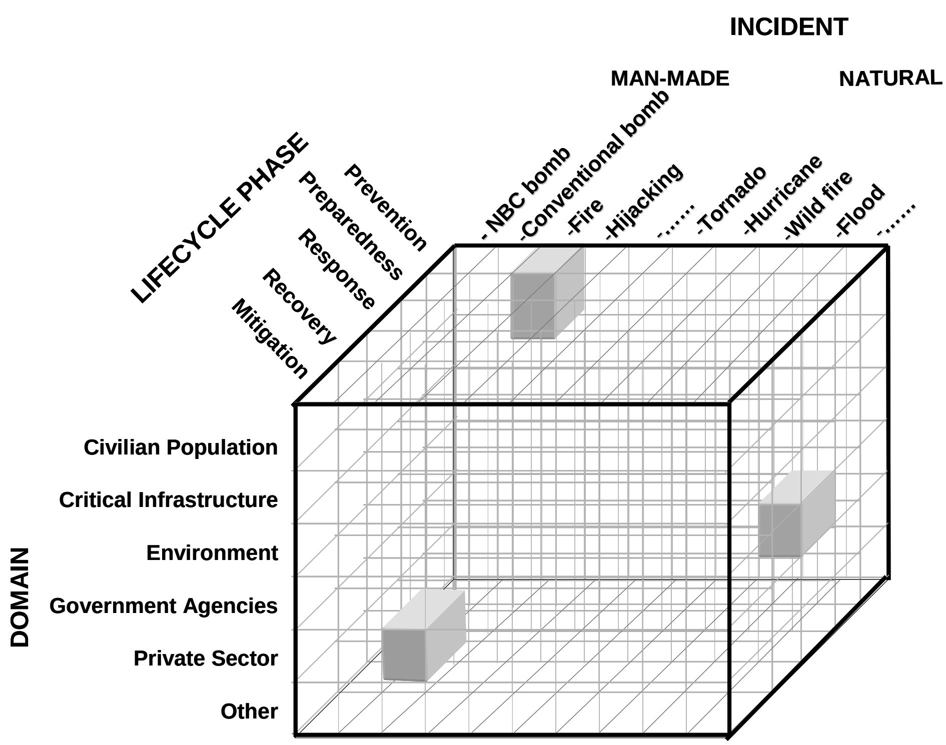

Figure 1. Framework for Incident Management (FIM)

The framework also identifies the need for M&S applications for supporting an event at each phase in its totality. In the above example, M&S capabilities addressing each of the affected and involved domains can jointly provide the ability to analyze and support an event from a holistic viewpoint. The M&S capabilities for such a holistic approach may be provided in a monolithic application or more likely through a number of applications, each covering one or more of the entities within identified domains, integrated using a distributed simulation architecture.

The framework partitions the application space and thus identifies the applications for simulation and gaming modules. An examination of framework indicates that many of the same components will be required to meet the needs of applications represented in different cells. For example, crowd simulation component may be required in all the cells that include the civilian population domain as one of the axes. A separate scheme is hence required to partition the solution space in to standard components. A conceptual architecture is presented in the next section for just such a purpose.

5. Conceptual Architecture

Simulation and gaming-based technologies can together provide a highly effective means for incident management training if integrated correctly using an appropriate architecture. A software architecture describes a software system as a configuration of components and connectors [14]. The conceptual architecture presented here focuses on the configuration of components with only brief treatment of the connectors.

5.1 Requirements

The architecture for simulation and gaming for incident management training should provide the following major capabilities:

- Creation of a federation of simulation and gaming modules appropriate to represent the selected incident management scenario.
- Integration among heterogeneous simulation federates modeling interrelated aspects of the emergency event.
- Integration among heterogeneous gaming modules with trainees role-playing within the same locale in the emergency event simulation.
- Synchronization between the simulation and gaming modules.

- Control over integrated execution of simulation and gaming modules through a training manager console.
- Execution in Massively Multi-player Online Games (MMOG) mode to support a large multi-agency incident management exercise.
- Access to heterogeneous data servers for supporting simulation and gaming modules.
- Management of MMOG execution.
- Management of simulation federation execution.
- Reusability of simulation and gaming module components.

5.2 Concept

A conceptual architecture to meet the above requirements is presented in Figure 2. The architecture will have two major subsystems – one for simulation and the other for gaming. The simulation components will each represent

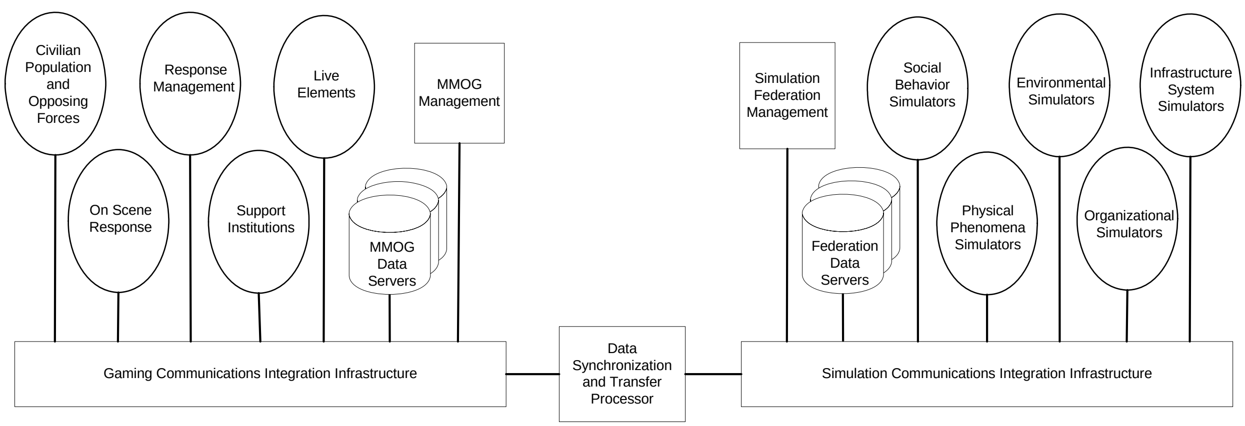

Figure 2. Architecture concept for Simulation and Gaming Incident management Training System

one of the major aspects of the emergency event or its response and will be based on defined behaviors of involved entities. The gaming components will provide for role-playing by emergency responders in roles represented in the figure. Simulation and gaming subsystems may have their individual communication integration infrastructure. The two infrastructures may be linked through a data synchronization and transfer processor as shown in the figure.

The components have been defined based on domain analysis and are intended to be comprehensive in their coverage of the incident management area. The analysis is based on academic and practitioner literature search and authors' interactions with incident management practitioners and researchers at a number of direct meetings, workshops, conferences and homeland security exercises over past several years. Authors' have also participated in development of prototypes of incident management simulations in collaboration with other researchers.

The simulation subsystem will contain a number of components within each of the groups shown in figure 2. The individual components will execute a model of an aspect of the incident or response and will interact with other components based on the scenario. The components will also interact with the data servers and will be controlled by the simulation federation management. The data servers will include one for Geographical Information Systems (GIS) data. Such data will be used as input to simulation components and for visualization of simulation outputs. All the interactions will go through the simulation communications integration infrastructure.

The gaming subsystem will also contain a number of components within each of the groups shown in figure 2. Trainees will immerse themselves into the scenario using the modules as game clients. They may interact with other trainees on other game clients and with entities that are controlled by simulation components. The gaming components will also interact with the data servers for the required data to execute the games. The information would include the detailed 3-D descriptions of the locales at and around the location of emergency incident. The locale 3-D geometry data will be accessed as warranted by the simulated movement of the trainees around the simulated area. The interactions will occur logically in the game environment and physically over the gaming communications integration infrastructure.

The proposed conceptual architecture will allow the training environment to be configured to a defined scenario using relevant simulation and gaming components. The architecture concept should also allow flexibility in hardware systems for executing the training environment. The system components will be distributed across a network of machines when training a large team. They should also allow setting up as multiple processes executing on a multi-tasking operating system such as Microsoft Windows on a standalone machine for training an individual.

The gaming and simulation worlds have been organized in separate sub-systems to separate out the real-time interactions of gaming with potentially non-real-time execution of simulations. A bridge has been proposed to join the two worlds, i.e., simulation and gaming. The problems involved in integrating simulations and gaming have been well-studied and, in fact, commercial products are available that address defense oriented implementations of the two worlds. It may be noted though that in addition to such integration, challenges for interoperability and composability discussed in section 5.5 need to be addressed for realization of the proposed architecture.

5.3 Simulation Integration Infrastructure

The simulation integration infrastructure may be based on HLA. HLA is a standard, originally initiated by the DoD, for implementing distributed simulation [15]. In HLA terms, the individual simulations are called federates and the distributed simulation is referred to as a federation. The HLA defines a framework by which individually executing federates can be combined into a distributed simulation federation.

The HLA framework has three major parts. The first part is a set of rules that federates and federations must adhere to ensure that a federation operates properly. The second part is a software system called the Run Time Infrastructure (RTI). The RTI defines an interface that provides a number of services that federates can use to communicate (i.e., exchange simulation data), and coordinate their execution (i.e., synchronize simulation clocks) with other federates in a federation. The third part of the HLA is called the Object Model Template (OMT). The OMT provides a means for describing the format of the data that will be exchanged between federates. For more information on distributed simulation using HLA, see [16].

HLA may need to be enhanced to meet the requirements for the incident management training environment including the need to synchronize with the gaming subsystem. For example, a pre-definition of the Federation Object Model (FOM) representing all the objects used by federates is required by HLA. This requires a large set up time for creation of the federation. A distributed scheme similar to that used in [17] may be useful to reduce the set up time and thus enable plug compatibility.

5.4 Game Integration Infrastructure

The gaming communications integration infrastructure is shown separately in the conceptual architecture to indicate that it may use a different paradigm than used by the simulation sub-system. It may use same one, i.e., the HLA/RTI with appropriate modifications for supporting gaming as defined by Cai et al [18]. It may use a different one such as a client server architecture traditionally used for Massively Multi-player Online Gaming (MMOG). The massive scale of these games has led to distributing the server load on a set of machines arranged in a grid or a cluster. Similar to the HLA discussion above, the MMOG architecture will need to be enhanced to meet the requirements of incident management training and the need to synchronize with the simulation subsystem components.

In the game world, there is no standard approach corresponding to the HLA RTI that can be used to integrate multi-player games. For various reasons including cost, performance and complexity, the HLA RTIs have been considered unsuitable by game developers [19]. Perhaps the primary reason that the game world has been less than enthusiastic about HLA is their need for real-time performance. Commercial games may trade realism, validity and accuracy for improved game experience [19]. HLA can help guarantee that simulations behave in a technically correct manner, e.g., messages arrive at recipient in proper order, but in doing so HLA implementations may sacrifice efficiency and performance to achieve technically correct behavior. Also in the HLA world, there is no requirement for centralized control or persistent data storage. Multi-player games typically need to centralize control and maintain game state data for long periods of time.

The development of a common integration infrastructure for gaming may take a while. Indeed some even doubt that a universally accepted interoperability protocol for games will emerge [20]. A few efforts have been carried out to utilize HLA for the purpose with modifications for game interfaces (see for examples, [22], and [23]). Other candidate architectures include those developed for distributed virtual reality environment such as DIVE[21] and MASSIVE[22]. Efforts to develop new architectures for the purpose have also been reported (see [23] and [24] for examples).

Although a common gaming integration infrastructure does not exist, there are some features that are typically used to integrate multi-player games. Features that will be briefly discussed include the client-server interaction model, proxies, arbitration, and socket-based communications.

- *Client-server interaction model* – The primary mechanism used for integrating multi-player games today is the client-server model. Peer-to-peer games have been implemented in the past, but it is unlikely that they will be used in the future. Players do not communicate with each other, but rather with the server. The client-server model is capable of supporting a large number of players, where the peer-to-peer model does not. In client-server game implementations, the server acts as a centralized control point for the game. Game action takes place on the server, but is reflected in the player's display on the local platform. The server is responsible for determining the advancement of time.
- *Proxies and arbitration* – The characters and action that the player views on the local platform is just a proxy for the real characters and actions that exist on the server. When the player moves a proxy character on the local platform, the server must verify that the move is acceptable. The server can later adjust the movement and

location of the character, if it determines that the move is not right. An action taken by a player on the local platform must be confirmed by the action on the server. The server as an arbitrator of game interaction and is the ultimate authority on determining game state. For example, if two players are involved in a battle, the server ultimately determines who wins and who loses.

- *Socket-based communications* – The most common mechanism used for communications between clients and servers in multi-player games are sockets. A socket is an endpoint of a two-way communication link between two programs running on a communications network. A socket is bound to a particular port number on a networked computer. The client and server programs write message packets to the socket for delivery to each other. Sockets guarantee the delivery of game data packets across the Internet.

5.5 *Challenges*

Realization of the proposed architecture presents some major challenges. The primary challenge is to ensure that the multiple models dealing with various aspects of the incident management scenario together form a coherent and unified representation. The component models should be capable of being reused in different scenario models. The data syntax and semantics among different models needs to be consistent. A "cloud" should either be represented the same way in different models or a translation mechanism should be provided for passing the information from one model to another. Also, the "cloud" in weather model should not be confused with a toxic "cloud" in a plume model. The time clocks and updates need to be synchronized among the different models that may be executing at different levels of abstraction. In addition to time synchronization, multi-resolution modeling will also require mediation for transferring of information across levels of abstraction.

Achieving a coherent model that can be used for a holistic simulation would require addressing the integratability, interoperability and composability of component models (see [25] for definitions and an associated framework). Standardized protocols such as HLA are necessary but not sufficient to achieve "meaningful interoperability" [26]. Several promising approaches are under development for achieving interoperability and composability. A graph theoretic approach has been suggested to determine the conceptual alignment of models [27]. Graph distance metrics are used to measure the alignment of metagraphs that represent the metamodels of components being intergrated. Trichotomic multi-resolution entities, comprising of information on world, conceptual and system models, have been proposed as mediators to align components [28]. Until such approaches become available, integration of component models would require significant effort for customized alignment.

Major issues associated with distributed multi-player games are how and when players receive information on fellow players' actions. Modeling of a large scenario can involve a large number of simulations and gaming clients flooding the network and nodes with state update messages. Time lags may occur between when a player initiates an action and when other players see the action. This latency causes problems in the execution of distributed games. The gaming communications integration infrastructure should be carefully designed to avoid such problems. The flexible update mechanism developed recently [29] may help address this challenge.

An associated challenge is the management of the training of people from different levels of incident management hierarchy. The best mode for training the first responders using a game client is to execute in real-time (i.e., time progress in game environment same as wall clock time). The best mode for training the incident managers and other personnel operating in Emergency Operation Centers (EOCs) may be segments of real-time execution interspersed with accelerated time (i.e., time progress in simulation environment faster than wall clock time) and fast forwards (i.e., simulated time jumping to a few hours or a day later). This mode will allow the EOC team to train in decision making over few simulated days of an unfolding emergency event while spending only a day in wall clock time. Combined training of first responders and EOC teams would require careful orchestration of time segments and fast forwards.

Combined training of people at different levels of hierarchy would require use of multi-resolution modeling, that is, a combination of simulations at macro and micro levels. There are multiple demanding challenges in multi-resolution modeling identified by Tolk [30] that will need to be addressed before the vision for integrated simulations can be realized. Even if valid models exist at each level of resolution, the challenge of cross resolution consistency, ensuring that sufficient correlation exists between the attributes at multiple levels of the same entity, will need to dealt with [31].

Distributed simulation architectures have come a long way with HLA as the current standard architecture for the purpose. On the other hand, MMOG architecture is still evolving. There is no standardization in this field as each game provider is using its own proprietary architecture. An open MMOG architecture will need to be developed that would allow plug compatibility of different gaming modules. The architecture should also allow plug compatibility of components of the core game engine also.

Massively Multi-Player (MMP) functionality involves the use of servers and is widely used in the gaming world. Due to its success as a commercial mechanism for distributed simulation and gaming, it should receive serious consideration for incident management applications. There have been security vulnerabilities associated with MMP games that have allowed players to cheat therefore appropriate safeguard must enacted. For more information on MMP technology, see [32].

Software licenses for game development systems and game distribution are often quite expensive. Pervasive use of this technology will require that many contractors of the United States Department of Homeland Security will need access to licenses to develop training applications. Perhaps hundreds of thousands of game-based training applications will ultimately be distributed. Game engine developers often collect royalties on each game sold. If commercial game engine software is used, the traditional business models of these software vendors may need to change.

6. Subsystems

The architecture description in the previous section showed two major subsystems, simulation and gaming, each with a number of major groupings. This section provides descriptions of the two major subsystems and their major groups. While the simulation components are discussed in detail listing a number of references, the gaming components are only briefly addressed partly to keep the focus on simulation and partly due to the lack of related academic literature.

6.1 Simulation subsystem

The simulation subsystem includes simulators that execute models of the major capabilities and phenomena involved in incident management as shown in Figure 3. Together these simulators will create the incident with all its major aspects and the responses by all the major agencies involved. The modeling of all the major aspects will capture the interactions, planned and random, that will create unanticipated situations that occur in the real world during an emergency incident. Thus the simulation subsystem will create the emergency incidents in the virtual world. The ability to represent the incident in the virtual world together with the associated major aspects and the creation of unanticipated interactions will provide a valuable training environment.

The simulators in the simulation subsystem will need to operate at a level appropriate to the training audience. It will be appropriate to simulate the incident and the response at a macro level for training of emergency managers if they are being trained alone. If only the emergency responders are being trained, the incident needs to be simulated at a micro level. To have both the emergency manager and responders experience the same incident muli-resolution modeling will be needed. For example, emergency managers would need to know the time it takes for response vehicles to get to an incident site. However they may not need to get into the detail of the traffic congestion they had to go through along the route to get there. The vehicle travel times can be determined through a macro level simulation that may require determining the route from dispatch point to incident site and determine the travel time based on the distance and congestion factors based on the time of the day. On the other hand, for training a responder in the same scenario, the actual drive may need to be modeled. The responding unit may need to experience going through the traffic and facing the movement of individual cars. A micro level simulation will be needed in this case.

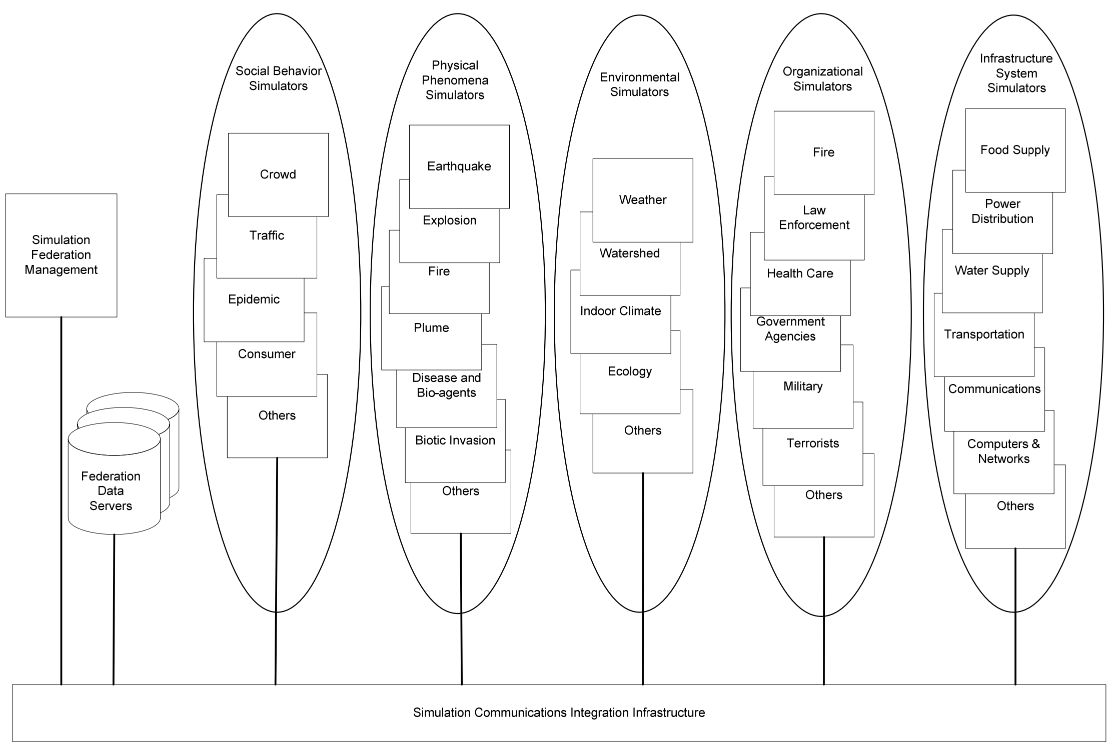

Figure 3. Simulation subsystem and its components.

The description of the simulators below provides a brief description of their capabilities. For brevity, the functionality at macro and micro levels is not discussed. An increase in level of detail from macro to micro simulation similar to the traffic simulation example above can be envisaged. Each of the modules should include capability for empirical and detailed simulation.

6.1.1 Social Behavior Simulators

The social behavior simulators will simulate phenomenon based on actions of multiple individuals. These include simulators for crowd, traffic, epidemic and consumer behavior. Other additional modules may be defined for social behaviors that are needed for specific situations. Each of the defined modules involves interaction of individuals leading to a collective behavior or phenomena. The use of modeling, in particular agent-based modeling, to study social behavior has drawn significant research over the past decade. Epstein and Axtell [33] proposed growing artificial societies using agent based models as a means to study social behaviors. Epstein [34] presented agent based modeling as a technique that permits one to study how rules of individual behavior give rise – or map up – to macroscopic regularities and organizations.

Social behavior simulators will be useful across all the application spaces defined in the Incident Management Framework in Figure 1. They will be of use for simulating the impact of all the incident types listed along the incident axis since generally the areas of primary concern would involve large population centers where social behaviors would have a significant role in containing or spreading the consequences. The simulators will be valuable across all the phases included on the lifecycle phase axis, albeit the simulators themselves may vary in the level of detail based on the objectives. Analysis of an incident with large footprint may require a high abstraction simulator based on system dynamics models, while those with smaller footprints may be amenable to detailed agent based models. All the domains listed on the third axis of the framework will gain from the use of social behavior simulators since the behaviors of the affected population will largely determine the actions required or impact on the modeled components within the domains. For example, a sudden panic in the population causing them to hoard basic supplies may affect the critical infrastructure and lead to emergency directives by the government agencies and measures by the private sector.

The major social behavior simulators are individually described below followed by examples of relevant recent reported research for each in Table 1. The table also includes remarks on the integration aspects of the models used in the respective papers.

1. *Crowd Simulators* should execute models of crowd movement at locations of interest under different event scenarios, crowd behavior and crowd management strategies. The locations of interest may include areas around actual and potential emergency incident sites, major business, commercial and residential areas that may be affected by evacuation directives, and major public transportation points such as bus and train stations, local rail transport stations, and airports. Different event scenarios may include normal, rush hour, terrorist attack, accidental fire, natural disaster, etc. Inputs may include street layouts including pedestrian areas, layouts within public buildings such as train stations and public parks, crowd volumes and density data, probabilities for stampede and casualties, weather conditions, location of emergency incidents, behavioral models of individuals, sensor data, and communications. Outputs may include location and status of specific individuals in the crowd, crowd volumes and density by city block and passages within public buildings and parks, crowd movement times between selected points, and crowd management systems data.
2. *Traffic Simulators* should execute models of general traffic flow and specific vehicle movements for a given region under different event scenarios (normal, rush hours, off-peak hours, terrorist attack, natural disaster, evacuation, etc.), driver behavioral models, and traffic management strategies. Inputs may include road network layout and characteristics, traffic management system description and status, individual vehicle locations and status, driver moods, historical traffic volume and vehicle density data, pedestrian data, probabilities for accidents, incidents, weather conditions, location of emergency incidents, behavioral models of vehicle operators, sensor data, and communications. Outputs may include locations and status of specific vehicles, traffic volume and densities by area or road segment, travel times between selected locations, accident data, and traffic management system data.
3. *Epidemic Simulation* is included within social behavior simulation as the spread of epidemic is highly dependent on social interactions. Inputs may include the demographic distribution in the region of interest, population interaction parameters, likelihood of epidemic spread under different conditions, strategies by health agencies for vaccination and containment, strategies by government agencies for public information

and containment, and weather conditions. Outputs may include a time profile of the spread of an epidemic and resulting need for health care, law enforcement and other services.

4. *Consumer Simulators* should execute models of consumer behavior following the occurrence of an emergency event. Inputs may include perceived and actual impact on essential supplies following an emergency event, consumer behavior patterns, demographic information together with purchasing power profiles, number, location, operating hours and inventory status for outlets of essential supplies. Outputs may include time profile of availability of essential supplies, consumer sentiment and behavior. There has been little work reported in literature on modeling consumer behavior following an emergency incident as reflected by only one associated reference in the table below.

Table 1. Recent publications on Social Behavior Simulation

S.No.	Reference	Application area	Modeling approach	Integration aspects
1	[35]	Building evacuation	Agent based	Highly modular C++ simulation engine should be amenable to integration.
2	[36]	Crowd behavior during emergencies	Agent based	Possible by making HLA function as a VHD++ machine to fit the VHD++ environment used for the simulator. [37]
3	[38]	Crowd simulation for emergency response	Agent based	Developed using AnyLOGIC, amenable to integration.
4	[39]	Traffic incident management	Discrete event	Simulation developed using Arena, integration can be achieved with some effort
5	[40]	Traffic simulation	Agent based	Successfully executed in distributed mode using Message Passing Interface (MPI)
6	[41]	Real-time traffic simulation	Continuum model	Successfully executed on a parallel architecture, hence amenable to integration.
7	[42]	Epidemic	Discrete event	Model developed using Python, hence amenable to integration.
8	[43]	SARS epidemic	Cellular automata and agent based	Model allows run time modifications of parameters and hence may have the basic

				structure for integration.
9	[44]	Gambian sleeping sickness spread	Numerical simulation	Numerical simulation expected to be difficult to integrate.
10	[45]	Regional economic impact of disaster	Computable General Equilibrium (CGE) Analysis	Implementation details not available to determine integration aspects.

6.1.2 Physical Phenomena Simulators

These simulators will model the physical phenomena involved in the creation and growth of the emergency incident. These may include such physical phenomena as earthquake, explosions, fire, chemical, biological or radiological plume, etc. These simulators will provide the extent of the damage while other simulators may model the impact of the damage on the associated systems. For example, the earthquake simulators will predict the extent of damage to the road network; the transportation system simulator (defined later in infrastructure simulators) will model the impact on transportation at a high level while the traffic simulator will simulate the impact on traffic resulting from the damaged road network at a detailed level. The simulators described below include the major physical phenomenon relevant to incident management. Other modules may be defined as needed.

1. *Earthquake Simulation* component should utilize a model of occurrence of earthquakes, the resulting damage to physical structures and associated casualties. Inputs may include description of critical infrastructure elements in the region of interest, their vulnerability to earthquakes, the description of major buildings and facilities and their human occupancy profile for different times of the day, the probability of occurrence of earthquakes of different magnitudes, the location of other assets of interest (vehicles, etc.) inside and around the structures. Outputs may include the identification of region affected by earthquake, the damage to different elements of infrastructure (road network, power distribution, communications, etc.), the damage to buildings and facilities, the number and kind of human casualties in the affected region, identification of damaged assets and the extent of damage.

2. *Explosion Simulator* component should execute a model of damage to structures and casualties resulting from explosions of different magnitudes. Inputs may include description of physical structures, their vulnerability to explosions of different magnitudes, human occupancy profiles for different times of the day, the location of other assets of interest inside and around the structures. Outputs may include the identification of structures affected by the explosion(s), the damage to different elements of infrastructure (road network, power distribution, communications, etc.), the damage to buildings and facilities, resulting fires in the structures considered, resulting plumes from the explosion, the number and kind of human casualties within and around the affected structure, identification of damaged assets and the extent of damage.
3. *Fire Simulation* component should simulate the damage to structures and casualties resulting from fire. Inputs may include description of physical structures including characteristics relevant to spread of fire (contents and inflammability), initiation and location of fire (accidental, intentional with fire accelerants, fire bombs, explosions, etc), human occupancy profiles for different times of the day, location of other assets of interest inside and around the structures, and weather conditions. Outputs may be similar to the two modules in this group discussed above.
4. *Plume Simulation* component should execute a model of the dispersion of plumes of various kinds including chemical, biological and radiological agents. Inputs may include the characteristics of the agent released, release mechanism used, the location of release point, terrain and structures around the release point, and weather conditions. Inputs may alternately be based on the sensor readings over time in the area of interest indicating the presence of an agent and the direction(s) of the spreading plume. Outputs may include time profile of the plume, and exposure profile for the population in the region affected by the plume over time.
5. *Disease and Bio-agents Simulation* component should simulate spread of diseases and bio-agents based on physical phenomenon, such as release of a bio-agent using a crop duster plane over a populated area. For some diseases, this component may model the initial spread of the disease based on physical phenomenon followed by the use of epidemic simulation component to model further spread of the disease based on social behavior. Inputs may include the characteristics of the disease virus, bacteria or bio agent, method of release or introduction of the agent into the environment, location of release point, demographics of the

region of interest including the vulnerability to the particular agent, and weather conditions. Outputs may include the spread of the agent and exposure profile for the population over time.

6. *Biotic Invasion Simulation* component should execute a model of the spread of biotic invasions such as malicious introduction of predatory species into the local environment with significant economic impact. Inputs may include the characteristics of the species, the description of land or water mass where the species was introduced, the land and water system interconnections, the population of local species that may be affected by the predatory species, and characteristics of efforts to stop the spread of the predatory species. Outputs may include the spread or decline of the biotic invasion over time.

Table 2. Recent publications on Physical Phenomena Simulation

S.No.	Reference	Application area	Modeling approach	Integration aspects
1	[46]	Earthquake simulation	Parallel numerical simulation	Parallelization structure used would allow integration.
2	[47]	Simulation of avalanches due to earthquake	Numerical simulation	Parallelization structure used would allow integration.
3	[48]	Earthquake simulation	Finite fault model	FINSIM tool developed using FORTRAN, difficult to integrate.
4	[49]	Blast simulation	Numerical simulation	Code developed in FORTRAN90, difficult to integrate.
5	[50]	Explosion simulation	Process simulation	Used HYSYS simulation software with an object oriented architecture that is amenable to integration.
6	[51]	Explosion simulation	Computational fluid dynamics	Used CFX5.7 software. May be integrated through communication of results.
7	[52]	Fire simulation	Cellular automata	Model based on Cell-DEVS using DEVSJAVA and hence amenable to integration
8	[53]	Forest fire simulation	Cellular automata	Model developed using DEVSJAVA and

				hence amenable to integration
9	[54]	Fire simulation	Agent based simulation	Developed using Virtools, should be amenable to integration.
10	[55]	Toxic gas plume simulation	Numerical simulation	Developed using RAMS written in FORTRAN77 and may be difficult to integrate
11	[56]	Pesticide product plume simulation	Computational Fluid Dynamics	Numerical simulation, difficult to integrate.
12	[57]	Plume simulation	Numerical simulation	Numerical simulation and proprietary interface, difficult to integrate.
13	[58]	Anthax spore dispersion simulation	Numerical simulation	Implemented in FORTRAN and may be difficult to integrate
14	[59]	Simulation of virus spread through airflow	Numerical simulation	Numerical simulation, difficult to integrate.
15	[60]	Simulation of bacteria growth through water system	Numerical simulation	Developed using C++ and should be amenable to integration.
16	[61]	Fish species invasion simulation	Numerical simulation	Numerical simulation, difficult to integrate.
17	[62]	Simulation of species in a metacommunity	Numerical simulation	Numerical simulation, difficult to integrate.
18	[63]	Simulation of alien plant invasion	Numerical simulation	Numerical simulation, difficult to integrate.

6.1.3 Environmental Simulators

These simulators will model the environmental phenomena that may affect the growth or containment of the emergency incident, its impact on the population or the efforts by responding agencies. Such environmental phenomena include weather, watershed, indoor climate, and ecology. These simulators will model these phenomena and provide the outputs to other simulators for modeling the impact. For example, the weather simulator will model the weather pattern over the duration of simulation; the fire simulator will model the growth or reduction in the fire due to weather conditions, while the fire department simulator (described later in organizational simulators) will model the impact on fire fighting efforts due to weather conditions. These simulators are described below.

1. *Weather Simulation* component should execute a model of the weather conditions during the simulation horizon. Inputs may include the initial conditions and the probability of incoming weather systems of different types (clouds, storms, winds, etc.). Outputs may include the change in weather conditions over the simulated horizon including wind speeds and directions, temperature, pressure changes, and precipitation.
2. *Watershed Simulation* component should simulate the watershed systems of the region of interest and its impact on the growth or containment of the emergency incident. This component will be needed for incidents such as release of toxic agents in water systems by terrorists, or release of predatory foreign species. The inputs may include the description of watershed systems in the region of interest, the links and flows between different parts of the watershed system, and the weather conditions. The outputs may include the spread of the introduced agents or species through the watershed system.
3. *Indoor Climate Simulation* component should simulate the climate systems within buildings and other structures occupied by people. This component should simulate the spread of air-borne agents introduced through indoor climate systems. Inputs may include the description of the duct systems including the intakes and vents, the capacity of the system, the location and sizes of door, windows and other openings, the method of introduction of air-borne agents (through air intake, through windows, doors), the characteristics of the air-borne agent and the occupancy profile of areas of the building/structure. Outputs may include the concentration of the agent in different areas through the building/ structure over time.
4. *Ecology Simulation* component should simulate the ecological system in the region affected by an emergency incident. For example, this component should model the effect of a toxic plume on the ecology of the area exposed. Inputs may include the characteristics of the toxic released in the region of interest, the composition of the ecology of the area including the landscape, watershed, plant and animal species in

the area, and the weather patterns. Outputs may include the time profile of impact on the ecology due to the release of the toxic.

Table 3. Recent publications on Environmental Simulation

S.No.	Reference	Application area	Modeling approach	Integration aspects
1	[64]	Environmental simulation	Cellular automata	Developed using JAVA and hence amenable to integration
2	[65]	Hurricane simulation	Numerical simulation	Numerical simulation, difficult to integrate.
3	[66]	Weather simulation	Numerical simulation	Parallelized code, amenable to integration.
4	[67]	Watershed simulation	Numerical simulation	The numerical simulation is encapsulated within a C++ interface and may allow integration in a distributed set-up..
5	[68]	Watershed simulation	Numerical simulation	Integrated set of models that may allow integration in a distributed set-up.
6	[69]	Flood operations simulation	Numerical simulation	Model parallelized and hence amenable to integration.
7	[70]	Simulation of virus transmission through building drainage and ventilation	Numerical simulation	Numerical simulation, difficult to integrate.
8	[71]	Indoor contaminant flow simulation	Numerical simulation	Integrated models and hence may be amenable to integration in distributed mode.
9	[72]	Indoor particulate movement simulation	Numerical simulation	Numerical simulation, difficult to integrate.
10	[73]	Fish ecosystem model	Numerical simulation	Model parallelized and hence amenable to integration.

11	[74]	Marine ecosystem model	Numerical simulation	Model embedded in another model and hence may be amenable to integration.
12	[75]	Seaweed expansion simulation	Discrete event simulation	Model integrated with other simulations and hence amenable to integration.

6.1.4 Organizational Simulators

These simulators will model the actions of the organizations involved in any aspect associated with the incident. The organizations modeled may include the fire, law enforcement, health care, other government agencies and the terrorist organization. The simulators will execute models of the flow of information within the organization, flow of authority and decisions and the resulting actions. It will utilize the relevant policies and procedures to model the behavior of the organization and its members. The number of publications reporting simulators in this category was found to be much smaller than other categories in the conceptual architecture. A list of recent relevant publications has been provided in table 4. These simulators are described below.

1. *Fire Department Simulator* component should simulate the actions of the fire department in response to an emergency incident including the assignment of resources for response, the actions of the fire crew at the incident site, handling of any casualties among fire crew and any subsequent requests for additional resources. Inputs may include the description of the emergency incident (location, magnitude, etc.), the time profile of the incident (determined by other simulators such as the growth of a fire by the fire simulator), the number of people trapped inside the affected structure, the number and profile of assets of interest within and around the affected structures, the information available from the associated 911 call, availability of fire department resources at responding locations, probability of fire crew casualty associated with incident magnitude and the affected structures, and directives from law enforcements (such as presence of terrorists at the site preventing the fire crew from entering the incident zone). Outputs may include the number of people rescued from affected structure, the response time by the fire department, actions taken and the injuries suffered by the fire crew. Other simulators such as the fire simulator may model the impact of actions of the fire crew. For example, the fire department simulator will model the number of water hoses pointed at the fire, while the fire simulator will model the reduction in the spread of

fire based on the water delivery rate and the magnitude of the fire. The two simulators will thus interact closely to model the unfolding events until the fire is put out completely.

2. *Law Enforcement Simulation* component should execute models of the actions of law enforcement agencies in response to an emergency incident including the assignment of resources for response and investigation, the actions of personnel at the incident site including engaging in any shootouts and high-speed chases against terrorists, and request for additional resources based on the unfolding events. Inputs may include the description of the emergency incident (location, magnitude, etc.), the time profile of the incident (determined by other simulators such as the terrorist actions by the terrorist organization simulator), the number and location of civilians involved (such as hostages held by terrorists, the number and profile of other assets of interest within and around the affected structures, the information available from the associated 911 call, availability of law enforcement resources at responding locations (personnel at different skill levels such as sharp shooters, vehicles, weapons, etc.), probability of law enforcement personnel casualty associated with incident nature (shootouts, use of explosive, falling structures due to earthquake aftershocks), and information from other response organizations (such as magnitude of fire preventing law enforcement officials from entering a burning structure). Outputs may include the actions by the law enforcement agents over time including response times of different agencies. The impact of the actions may be determined through interactions between the law enforcement simulators and other relevant simulators such as terrorist organization simulator, traffic simulator and crowd simulator. The literature search indicated limited efforts that specifically addressed this component.

3. *Health Care Simulation* component should execute models of the actions of the health care organizations (including emergency medical technicians, hospitals) in response to an emergency incident including the deployment of resources and actions for triage and treatment of injured at the incident site, movement of casualties to hospitals, and treatment at the hospitals. Inputs may include the number, location and type of casualties from an emergency incident, the availability of staff at work and off (on-call), the availability of resources (own and those that can be acquired quickly from surrounding jurisdictions), the time and resources required for attending to each casualty type, and the probabilities of death from different casualty types over time. Outputs may include the operation of the health care system over time including the

number of people treated and released, admitted, dead, waiting for treatment, and the state of the staff and facilities (to determine their capability to deal with another incident).

4. *Government Agencies Simulation* component should simulate the operations of local, state and federal government agencies that are involved in incident management including state emergency management agency, Federal Emergency Management Agency (FEMA), Department of Health and Human Services (HHS), and Center for Disease Control and Prevention (CDC). The execution of the emergency support functions including communication, warnings, emergency public information, evacuation and mass care should be modeled. Inputs may include the role, processes and procedure followed by the agency and the number, characteristics and location of resources under its purview. Outputs may include the results of actions of the agencies modeled including the availability of emergency services to affected population over time.

5. *Military Simulation* component may be used for simulating military and National Guard operations when the magnitude and nature of the incident requires military deployment. In particular, military resources may be requested in response to a Weapons of Mass Destruction (WMD) incident for decontamination, medical support, rapid mobilization and mass logistics. Inputs may include the role, processes and procedure followed by the military and the number, characteristics and location of its resources. Outputs may include the results of actions of the military over time including such metrics as number of people decontaminated, number of casualties processed by the medical support team and people evacuated. No references were found in the academic literature that specifically modeled military in emergency response role.

6. *Terrorists Simulation* component should execute models of the actions of terrorist organizations for setting up and carrying out primary and secondary attacks. It should have the ability to model a range of attack scenarios including suicide bombing, use of WMD devices, conventional explosives, release of biological and chemical agents, and armed attacks. Inputs may include the primary and alternate action plans, the number and roles of terrorist resources, the number, type and location of resources available to the terrorist organization, and the level and percentage of sympathizers to the terrorist cause around the area of planned attack. Outputs may include the results of the terrorist actions defined by damage to critical infrastructure, damage to structures of significance, civilian and military casualties, terrorist casualties, and arrests.

Table 4. Recent publications on Organizational Simulation

S.No.	Reference	Application area	Modeling approach	Integration aspects
1	[76]	Ship fire response simulation	Timed Petri Nets	Model built using Prolog based software, expected to be difficult to integrate.
2	[77]	Forest fire fighting simulation	Discrete and continuous simulation	Models integrated using HLA. Already set up for distributed simulation.
3	[54]	Fire fighting simulation	Agent based simulation	Developed using Virtools, should be amenable to integration.
4	[78]	Crowd control simulation	Numerical simulation	Difficult to integrate.
5	[79]	Simulation of coordination among police units	Social simulation	Simulation exercise with live participants, cannot be integrated.
6	[80]	Emergency dispensing clinics simulation	Discrete event simulation	Simulation integrated with optimization routine, hence amenable to integration.
7	[81]	Simulation of health care system response to bioterror	Discrete event simulations	Models developed using MedModel and Borland Delphi, should be amenable to integration.
8	[82]	Simulation of emergency department	Discrete event simulation	Model developed using ARENA, should be amenable to integration.
9	[83]	Simulation of response to anthrax attack	Discrete event simulation	Model developed using Rethink, should be amenable to integration.
10	[84]	Simulation of organizations in emergency response	Agent based simulation	Models designed for integration in distributed framework.
11	[85]	Disaster response	Agent Based	Expected to be amenable to integration.

		organizational simulation	Simulation	
12	[86]	Simulation of disaster and response strategies	Discrete event simulation	Model developed using AweSim, should be amenable to integration.
13	[87]	Simulation of terrorist organization	Agent based simulation	Model developed using PASION, may be difficult to integrate.
14	[88]	Simulation of terrorist network	Agent based simulation	Should be amenable to integration.
15	[89]	Simulation of terrorist network	Numerical simulation	Developed using PERL, may be amenable to integration.

6.1.5 Infrastructure System Simulators

These simulators will execute models of the behavior of the infrastructure systems following the occurrence of an emergency incident. They will simulate the propagation of the impact of damage through out the infrastructure system based on the damage to one part due to the emergency incident. For example, the earthquake simulator may predict the destruction of food warehouses in the affected region. The food supply simulator will model the diversion of food shipments from other regions to the affected region. These simulators are described below with a list of recent relevant publications provided in table 5.

1. *Food Supply Simulation* component should execute models of food supply infrastructure including the movement, storage and distribution of food supply to affected population. Inputs may include the damage to the food supply infrastructure, the availability of food supplies in the surrounding regions, probabilities of disruptions in food supply, probabilities of deterioration in food supplies, and the resources available for food supply distribution. Outputs may include the profile of food supply over time to the affected region, the deterioration of food supplies in storage, and the shortages. A crowd simulator, for example, may use the outputs from this simulator to model rioting situations caused by food shortages.
2. *Power Distribution Simulation* component should simulate the behavior of the power distribution infrastructure including the interruption and restoration of power supply to regions affected by an

emergency incident. The model will be used to predict the behavior of the power grid following damage to one part, to determine the application of resources for restoration and to determine the time for power restoration. Inputs may include the description of power grid with its characteristics, the vulnerabilities in the power grid, and the resources available in immediate and surrounding regions. Outputs may include the profile of power supply and outages in the affected region over time.

3. *Water Supply Simulation* component should represent the behavior of the water supply infrastructure including the interruption, restricted operation and restoration of water supply to regions affected by an emergency event. The model should include the impact of a terrorist attack on the water supply system such as contamination of water supply. Inputs may include the description of the water supply system including the water sources, the collection, filtration and distribution system, the operation and maintenance resources available, the links to other critical infrastructure systems including power distribution, road and rail networks. Outputs may include the volume and quality profile of the water supply in the affected region over time.

4. *Transportation Simulation* component should mimic the transportation system infrastructure including highways and road network, rail network, waterways, marine and air transport. It should model the impact of man-made or natural disasters on the transportation infrastructure. Inputs may include the description of the transportation system infrastructure together with its network, characteristics of node points, traffic volumes across arcs and through the nodes, traffic control mechanisms, failure characteristics of major control mechanism and equipment, operation and maintenance resources, multi-modal links and links to other critical infrastructure. Outputs may include the impact of modeled emergency events on the operation of the transportation infrastructure over time.

5. *Communications Simulation* component should reproduce the impact of emergency events on simulated communications infrastructure including wired and wireless telephone links, microwave and satellite based communications, and radio and television broadcasts. Inputs may include the description of the communications infrastructure together with the locations and types of assets such as phone lines, communication towers, radio and televisions stations, links to other critical infrastructure, failure characteristics, and operation and maintenance resources. Outputs may include the impact of modeled

disaster events on the operation of the communication infrastructure over time defining interruptions, limited operation and restoration to full operation capabilities.

6. *Computer & Networks Simulation* component should execute models of computer and network operations under the impact of the modeled emergency events including any cyber-attacks. Inputs may include the description of the computing and network infrastructure together with the security mechanisms used, reliability information, links to physical components and critical locations, procedures for creating and using back-up systems, and operation and maintenance resources. Outputs may include the impact of the modeled event or cyber-attack on the operation of the computing and networking infrastructure over time describing the interrupted capabilities and operations, limited operations, loss of data, restoration of data, and restoration of the systems to full operation capabilities.

Table 5. Recent publications on Infrastructure Simulation

S.No.	Reference	Application area	Modeling approach	Integration aspects
1	[90]	Simulation of critical infrastructure dependencies	System dynamics	Difficult to integrate.
2	[91]	Critical infrastructure reliability modeling	System dynamics	Difficult to integrate.
3	[92]	Food distribution in area affected by disaster	Agent Based Simulation	Based on an object oriented software, MANA [93] amenable to integration.
4	[94]	Contamination in food supply chain	State transition simulation	Model developed in Delphi 5, amenable to integration.
5	[95]	Inventory management for relief operations		Simulation developed using Arena, integration can be achieved with some effort
6	[96]	Power distribution control	Agent based simulation	Based on object oriented software and hence amenable to integration
7	[97]	Power distribution control	Agent based simulation	Based on JADE, hence amenable to integration.

8	[98]	Power system stability analysis	Hybrid simulation	Distributed simulation and hence open to integration.
9	[99]	Residential water supply simulation	Agent based simulation	Based on JADE, hence amenable to integration.
10	[100]	Urban water management simulation	Agent based simulation	Based on JAVA and Swarm libraries, hence amenable to integration.
11	[101]	Security of a water supply network	Numerical simulation	Difficult to integrate.
12	[102]	Intelligent transportation system simulation	Discrete event simulation	Based on DeSim (C++ for DEVS implementation), should be amenable to integration.
13	[103]	Advanced traffic management simulation	Discrete event simulations	Based on Paramis and DYNASMART, difficult to integrate.
14	[104]	Emergency evacuation planning	Discrete event simulation	Based on CORSIM, difficult to integrate.
15	[105]	Wireless and Wireband Network simulation	Discrete event simulation	Based on SMPL, difficult to integrate.
16	[106]	Network traffic simulation after disaster	Discrete event simulation	Simulation developed in research tool NS Simulator, difficult to integrate.
17	[107]	Network security simulation	Discrete event simulation	Simulation capable of parallel and distributed execution and can be integrated.
18	[108]	Next Generation Network evaluation	Discrete event simulation	Model also implemented in OPNET that is amenable to integration.

		for emergency communications		
19	[109]	Denial of service attack simulation	Discrete event simulation	**** Requested through ILL****

6.2 Gaming Subsystem

The purpose of the gaming subsystem is to provide an immersive incident management environment in which users, i.e., players can interact with each other, and with simulated systems and organizations described in the previous section. The video game development community has become a leading innovator in the use of graphics, audio, and force feedback to create virtual worlds. Multiplayer game technology allows many players to interact in the same virtual world across the Internet. As such, it is only natural to look to the technology leaders for solutions to creating the front-end interface to a virtual incident management environment.

Elements of the video game-based training systems would include, where appropriate, real-time computer generated graphics and audio. Objects represented would include the environment, the incident scene, various emergency response vehicles, affected population, equipment, emergency responders, etc. Emergency responders would include various characters that represent the fire department, urban search and rescue, health care, law enforcement and terrorists. Physics models and artificial intelligence would be used to give objects physically correct behaviors and movements, or enable them to act autonomously without human intervention.

The game engine, associated simulation modules, and reusable learning objects would be tested for security and certified by appropriate testing facilities (please see [110] for definition of reusable learning objects). The software would be secure and prevent the introduction of any security holes, viruses, worms, etc. onto the trainee's computer. The software also would not allow the student to achieve any unauthorized access to the host computer system areas or other networked systems as a result of the installation of the simulation-based training application.

Simulation-based learning applications could be developed for use in stand-alone mode or distributed multi-player mode to enable team training. Multi-student training applications would need distributed simulation capabilities to synchronize the software running on different platforms. Servers would be needed to store and distribute data to support these training exercises.

What functions does the gaming subsystem need to provide? Some of the key functions that need to be supported:

- Allow the creation of different game genres such as strategy, role-playing, and puzzle solving based on individual training needs
- Provide user interfaces that allow a variety of user input devices
- Animate characters and other objects
- Render graphics scenes, generate audio, and provide force feedback
- Sequence all processes in a timely fashion
- Implement intelligent behaviors for both player and non-player characters
- Coordinate multi-player game play across the Internet
- Enable user modifications, commonly referred to as "modding" in the computer gaming community, of the game environment through high level scripts
- Compile high level scripts into more efficient low level code
- Manage user sessions and security
- Provide a central repository for game assets or resources

Figure 4 shows the major elements of the gaming subsystem, i.e., clusters of game applications, game management, data servers, and communications infrastructure. The next sections discuss these elements briefly.

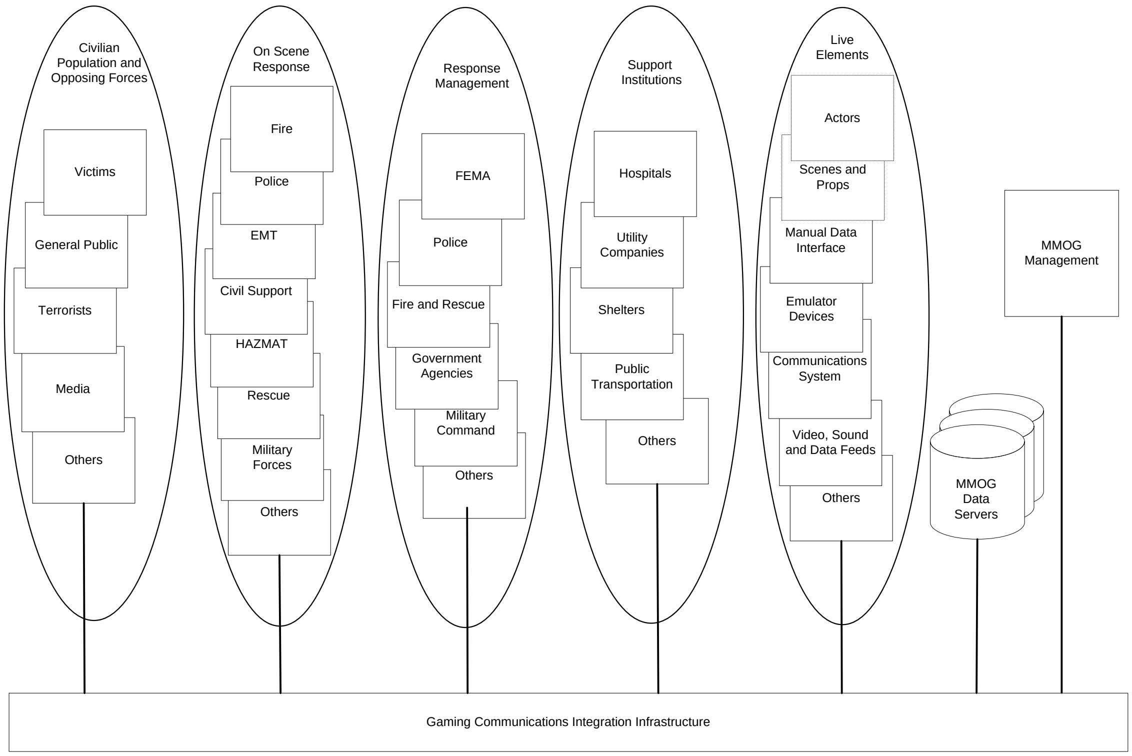

Figure 4. Gaming subsystem and its components.

6.2.1 Game Applications

Incident management gaming applications should be created to support the roles that users may need to play during an incident for training purposes. Five groups of roles and game interfaces have been initially identified as shown in figure 4. Other roles and interfaces might also be defined in the future. Each group is briefly described below:

- *Civilian Population and Opposing Forces* – Allows players to assume various roles of the civilian population affected by an incident and the opposing forces that may be involved in the case of a man-made incident. The opposing forces, that is, the terrorists, would normally mingle within the civilian population and may require several features that are common with other entities in this group. Some of the possible roles in this group include victims, general public, terrorists, and media personnel.
- *On Scene Response* – Players take on the roles of responders on an incident scene. They should be able to execute response tasks such as securing the perimeter of the affected area, crowd control, attending to victims,

identify continued threats, and containing spread of fire. Some possible roles include fire, police, EMT, civil support, HAZMAT, rescue, and military personnel.

- *Response Management* – Players assume the roles of management personnel of the responding agencies. They should be able to participate in a simulated Emergency Operations Center setting, have access to information and displays similar to a real life EOC at the appropriate level (local, state, federal), and make and communicate decisions. The decisions may be communicated to simulations executing the responses or to other players playing the role of first responders at the scene of the incident. Some possible roles include Federal Emergency Management Agency (FEMA), police, fire and rescue, other government agencies and military command.
- *Support Institutions* – These roles and interfaces allow the players to execute tasks carried out by personnel of institutions that play a supporting role in incident management. Players may treat victims at the emergency department, perform repairs on utility services affected by an incident, set up a shelter for people affected by an incident, set up and run transportation services for evacuation, etc. The possible roles include hospital, utility services, shelter, and public transportation.
- *Live elements* – The roles and interfaces enable the incorporation of live game play (outside of the virtual world), video feed, external communications channels, etc.

The above list of player roles and interfaces is only intended to be a sampling of what is possible. A game-style interface could be devised for almost any role within an incident management setting. Incident management resources include many case study scenarios that could form the basis for engaging game interactions in each of these areas.

There are limited publications in academic literature on gaming applications with most of them on response management as indicated in table 6. Couple publications were found on emergency health care as shown in the table. This area appears to have developed more in practice than in research as indicated by availability of such tools through websites (see [111] and [112] for examples) and reports of work at universities in popular press (see [113]).

Table 6. Recent publications on Gaming Applications for Incident Management

S.No.	Reference	Application area	Modeling approach	Integration aspects
1	[114]	Training for response in hazardous environment	Pre-run continuous simulation used to	Difficult to integrate in distributed framework.

			support live exercise	
2	[115]	Emergency response decision making	Discrete Event Simulation (DES) used to support live exercise	Difficult to integrate in distributed framework.
3	[116]	Management of chemical disasters and forest fires	DES used to support live exercise	Difficult to integrate in distributed framework.
4	[117]	On scene response training by Emergency Medical Technician (EMT)	Discretized continuous simulation interfaced with game client	Simulation and virtual reality integrated in a distributed framework.
5	[20]	On scene response, triage by EMT	Hybrid discrete event and continuous simulation	Uses client server architecture, difficult to integrate in distributed simulation framework
6	[118]	Emergency vehicle driver training	Discretized continuous simulation	Includes a set of integrated models and hence amenable to integration.

7. Conclusion

This paper presented a conceptual architecture for integrating gaming and simulation for incident management training with a focus on defining the components and associated recent literature. This integration is proposed to bring together the interactive environment provided by gaming for taking actions and making decisions for a situation with the capability to use simulation to produce technically correct impact of the actions taken and decisions made. The integration would allow the use of gaming for serious applications for the incident management community. Such serious gaming applications are expected to be quite effective for the coming generations of workforce that have grown up playing video games.

The research community needs to agree on a standard definition of these components to promote their independent development for future plug and play compatibility. Recent reported examples of models that appeared similar to the defined components were provided to identify the current available knowledge and gaps.

It is proposed that the architecture be implemented as a common infrastructure that can be used to integrate independently-developed simulation and gaming modules. The availability of such an infrastructure will strongly encourage development of gaming and simulation modules covering the breadth and depth of the incident management applications. Incident management personnel can select the modules applicable to their environment to create a capability to serve their training needs.

An implementation of the architecture would provide a useful test bed. It can be used to test the interoperability of incident management simulation and gaming applications. It can also be used to test the interfaces for such applications. The proposed test bed will be highly effective if supported with repositories for templates and test case data. Academic and commercial researchers can use the templates and test case data to quickly test out new developments. The test case data can also serve as a benchmark for comparison of alternate approaches for similar applications and thus further spur development and help incident management personnel by providing a common scale to rank vendor offerings.

Implementation of the architecture as a common infrastructure will require development of standards at several fronts including the data models, interfaces, distribution and synchronization mechanisms and user interaction devices. Current work in progress on integration of gaming and simulation is expected to lead to more such activity in the future.

References

[1] Jain, S. and C.R. McLean, 2003, *Modeling and Simulation of Emergency Response: Workshop Report, Relevant Standards and Tools*, National Institute of Standards and Technology Internal Report, NISTIR-7071. Available on line at www.nist.gov/msidlibrary/doc/nistir7071.pdf, last accessed on May 24, 2007.

[2] Department of Homeland Security, 2006, TOPOFF 3 Frequently Asked Questions, available on-line at http://www.dhs.gov/xprepresp/training/editorial_0603.shtm, last accessed on May 24, 2007.

[3] Sullivan, Thomas J., 1985, *Modeling and Simulation for Emergency Response*, Lawrence Livermore National Laboratory, Report No. UCRL 92001 Preprint.

[4] LANL, 2001, "Urban Security Project," http://www.lanl.gov/orgs/d/d4/aquality/urban.html, last accessed on May 24, 2007.

[5] LANL, 2000, “Interdependent Infrastructure Modeling, Simulation, and Analysis Project (SOFIA),” http://www.lanl.gov/orgs/d/d4/infra/sofia.html, last accessed on May 24, 2007.

[6] Steinman, J.S. and J.W. Wong, 2003, “The SPEEDES Persistence Framework and the Standard Simulation Architecture,” Proceedings of the Seventeenth Workshop on Parallel and Distributed Simulation (PADS’03), June 10-13, San Diego, California, 11-20.

[7] Tolk, A., and J.A. Muguira, 2004, "M&S within the Model Driven Architecture," Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), Paper 1477, December, Orlando, FL.

[8] Bowers III, F.A. and D.L. Prochnow, 2003. “JTLS-JCATS Federation Support of Emergency Response Training”, in: Proceedings of the 2003 Winter Simulation Conference, eds: S. Chick, P.J. Sanchez, D. Ferrin and D.J. Morrice. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey. pp 1052-1060.

[9] McDonald, J.T. and M.L. Talbert, “Agent-based Architecture for Modeling and Simulation Integration,” Proceedings of the National Aerospace & Electronics Conference (NAECON 2000), Oct. 10-12, Dayton, Ohio.

[10] Campbell, A.P. and J.R. Hummel, 1998, “The Dynamic Information Architecture System: An Advanced Simulation Framework For Military And Civilian Applications,” http://www.dis.anl.gov/DIAS/papers/SCS/SCS.html, last accessed on January 20, 2004.

[11] McLean, C.R., S. Leong and F. Riddick, 2000, “Integration of Manufacturing Simulations using High Level Architecture (HLA),” Proceedings of the 2000 Advanced Simulation Technologies Conference, April 16-20, Washington DC.

[12] Jain, S., and McLean, C.R., 2006. An Integrating Framework for Modeling and Simulation for Incident Management. Journal of Homeland Security and Emergency Management: Vol. 3: No. 1, Article 9.

[13] U.S. Department of Homeland Security, 2004, National Response Plan, Available on line at http://www.dhs.gov/interweb/assetlibrary/NRP_FullText.pdf, last accessed on January 5, 2006.

[14] Schneider, J., and O. Nierstrasz. 2000. Components, scripts, and glue. In Software architectures: Advances and applications, L. Barroca, J. Hall, and P. Hall, 13-25. London: Springer.

[15] IEEE, 2000, IEEE 1516 Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) – Framework and Rules, Institute of Electrical and Electronics Engineers, Piscataway, NJ, USA.

[16] Kuhl, F., R. Weatherly, and J. Dahmann, 1999, Creating Computer Simulations: An Introduction to the High Level Architecture, Prentice Hall, Upper Saddle River, NJ.

[17] McLean, C.R. and F. Riddick, 2000, "The IMS Mission Architecture for Distributed Manufacturing Simulation," in Proceedings of the 2000 Winter Simulation Conference, Orlando, FL.

[18] Cai, W., Xavier, P., Turner, S.J., and Lee, B.-S., 2002, A scalable architecture for supporting interactive games on the internet. In Proceedings of the 16th Workshop on Parallel and Distributed Simulation (PADS'02). 12-15 May, pp. 54 – 61.

[19] Möller, B., Löfstrand, B., Backlund, A., Waller, B., Lindqvist, J., and Virding, R., 2005. Gaming and HLA 1516 Interoperability within the Swedish Defense. 2005 Fall Simulation Interoperability Workshop, Simulation Interoperability and Standards Organization (SISO), Paper Number 05F-SIW-118.

[20] McGrath, D., and Hill, D., 2004. UnrealTriage: A Game-Based Simulation for Emergency Response. Huntsville Simulation Conference, Oct. 19-21.

[21] Frećon, E., and Stenius, M. 1998. DIVE: A scaleable network architecture for distributed virtual environments. Distributed Systems Engineering Journal, Vol. 5, No. 3, pp. 91-100.

[22] Greenhalgh, C., and Benford, S., 1995. MASSIVE: a distributed virtual reality system incorporating spatial trading. Proceedings of the 15th International Conference on Distributed Computing Systems. May 30 - June 2, 1995, Vancouver, British Columbia, Canada, IEEE Computer Society Press, ISBN 0-8186-7025-8, pp. 27-34.

[23] Bharambe, A., Pang, J., and Seshan, S., 2006. Colyseus: A Distributed Architecture for Online Multiplayer Games. 3rd Symposium on Networked Systems Design and Implementation (NSDI'06), May 8-10, San Jose, CA, pp. 155–168.

[24] McGrath, D., Hunt, A., and Bates, M., 2005. A simple distributed simulation architecture for emergency response exercises. In Proceedings of the Ninth IEEE International Symposium on Distributed Simulation and Real-Time Applications (DS-RT 2005), 10-12 Oct., pp. 221 - 226.

[25] Page, E.H., Briggs, R., and Tufarolo, J.A., 2004. Toward a family of maturity models for the simulation interconnection problem. In: Proceedings of the Spring 2004 Simulation Interoperability Workshop. IEEE CS Press.

[26] Tolk, A., Diallo, S.Y., Turnitsa, C.D., and Winters, L.S., 2006. Composable M&S Web Services for Netcentric Applications. Journal for Defense Modeling & Simulation (JDMS), Vol. 3 No. 1, p. 27-44.

[27] Yilmaz, L., 2007. Using Meta-level Ontology Relations to Measure Conceptual Alignment and Interoperability of Simulation Models. In: Proceedings of 2007 Winter Simulation Conference, Eds: S.G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J.D. Tew and R.R. Barton. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

[28] Tolk, A., and Turnitsa, C.D. , 2007. Conceptual Modeling of Information Exchange Requirements Based on Ontological Means. In: Proceedings of 2007 Winter Simulation Conference, Eds: S.G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J.D. Tew and R.R. Barton. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

[29] Zhou, S., Cai, W., Turner, S.J., Wei, J., and Zong, W., 2007. Flexible State Update Mechanism for Large-Scale Distributed Wargame Simulations. SIMULATION, Vol. 83, No. 10, p. 707 - 719.

[30] Tolk, A., 2006. Multi-resolution Challenges for Command and Control M&S Services. 2006 Spring Simulation Interoperability Workshop, Simulation Interoperability and Standards Organization (SISO), Paper Number 06S-SIW-007.

[31] Reynolds, Jr., P.F., Natrajan, A., and Srinivasan, s., 1997. Consistency maintenance in multiresolution simulation. ACM Transactions on Modeling and Computer Simulation (TOMACS), Volume 7, Issue 3, July, pp. 368 - 392.

[32] Alexander, T. (ed.), 2003, Massively Multiplayer Game Development, Charles River Media, Hingham, MA.

[33] Epstein, J.M., and R. Axtell, 1996. Growing artificial societies : social science from the bottom up. MIT Press, Boston, MA.

[34] Epstein, J.M., 1999, Agent-based computational models and generative social science. *Complexity*, 4:5, 41-60.

[35] Pan, X., C.S. Han, K. Dauber and K.H. Law, 2006, "Human and social behavior in computational modeling and analysis of egress." Automation in Construction. Volume 15, Issue 4 , July 2006, Pages 448-461.

[36] Musse, S. R. and Thalmann, D., "Hierarchical model for real time simulation of virtual human crowds", IEEE Transactions on Visualization and Computer Graphics, Vol. 7, No. 2, April-June 2001, pp. 152-164.

[37] Thalmann, D., 2006, personal communication.

[38] Shendarkar, A., K. Vasudevan, S. Lee, and Y.J. Son, 2006. Crowd Simulation for Emergency Response Using BDI Agent based on Virtual Reality. In Proceedings of the 2006 Winter Simulation Conference. eds. L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, pp. 545-553.

[39] Ozbay, K., and Bartin, B. 2003. Incident Management Simulation. SIMULATION, Vol. 79, No. 2, p. 69 - 82.

[40] Balmer, M., Nagel, K., and Raney, B. 2004. Large-Scale Multi-Agent Simulations for Transportation Applications. Journal of Intelligent Transportation Systems, Oct2004, Vol. 8 Issue 4, p205-221.

[41] Chronopoulos, A.T., and Johnston, C.M., 2002. A real-time traffic simulation using a communication latency hiding parallelization. IEEE Transactions on Vehicular Technology, Volume 51, Issue 3, May 2002 Page(s):498 – 510.

[42] Witten, G. and Poulter, G., 2007. Simulations of infectious diseases on networks. Computers in Biology and Medicine, Volume 37, Issue 2, February, p. 195-205.

[43] Hsieh, J.-L., Sun, C.-T., Kao, G.K.-Y., and Huang, C-.-Y., 2006. Teaching through Simulation: Epidemic Dynamics and Public Health Policies. SIMULATION, Vol. 82, No. 11, p. 731 - 759.

[44] Artzrouni, M. and Gouteux, J.-P., 2001. Population Dynamics of Sleeping Sickness: A Microsimulation, Simulation & Gaming, Vol. 32, No. 6, p. 215 - 227.

[45] Rose, A., Liao, S.-Y., 2005. Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions. Journal of Regional Science, Vol. 45 Issue 1, p75-112.

[46] Guo, Y., Jin, X., and Ding, J., 2006. Parallel numerical simulation with domain decomposition for seismic response analysis of shield tunnel. Advances in Engineering Software, Vol. 37 Issue 7, p450-456.

[47] Patra, A.K., Nichita, C.C., Bauer, A.C., Pitman, E.B., Bursik, M., and Sheridan, M.F., 2006. Parallel adaptive discontinuous Galerkin approximation for thin layer avalanche modeling. Computers & Geosciences, Vol. 32 Issue 7, p912-926.

[48] El-Engebawy, M.A., Chen, G., Rogers, J.D., Hoffman, D., Herrmann, R.B., 2004. Finite Fault Modelling of Near-Field Rock Motions in the New Madrid Seismic Zone. Journal of Earthquake Engineering, Vol. 8 Issue 5, p 699-724.

[49] Van den Berg, A.C., Weerheijm, J., 2006. Blast phenomena in urban tunnel systems. Journal of Loss Prevention in the Process Industries, Nov2006, Vol. 19 Issue 6, p598-603.

[50] Mohd Shariff, A., Rusli, R., Leong, Chan T., Radhakrishnan, V.R., and Buang, A., 2006. Inherent safety tool for explosion consequences study. Journal of Loss Prevention in the Process Industries, Sep2006, Vol. 19 Issue 5, p409-418.

[51] Sklavounos, S., and Rigas, F., 2004. Computer simulation of shock waves transmission in obstructed terrains. Journal of Loss Prevention in the Process Industries, Nov2004, Vol. 17 Issue 6, p407-417.

[52] Muzy, A., Innocenti, E., Aiello, A., Santucci, J.-F., and Wainer, G., 2005. Specification of Discrete Event Models for Fire Spreading, SIMULATION, vol. 81, No. 2, pp. 103 - 117.

[53] Ntaimo, L., Zeigler, B.P., Vasconcelos, M.J., and Khargharia, B., 2004. Forest Fire Spread and Suppression in DEVS, SIMULATION, vol. 80, No. 10, pp. 479 - 500.

[54] Dugdale, J., Pallamin, N., and Pavard, B., 2006. An assessment of a mixed reality environment: Toward an ethnomethodological approach. Simulation & Gaming, Jun2006, Vol. 37 Issue 2, p226-244.

[55] Buckley, R.L.. Hunter, C.H., Addis, R.P., Parker, M.J., 2007. Modeling Dispersion from Toxic Gas Released after a Train Collision in Graniteville, SC. Journal of the Air & Waste Management Association, March, Vol. 57 Issue 3, p268-278.

[56] Kefalas, D.A., Christolis, M.N., Nivolianitou, Z., and Markatos, N.C., 2006. Consequence analysis of an open fire incident in a pesticide storage plant. Journal of Loss Prevention in the Process Industries, January, Vol. 19 Issue 1, p78-88.

[57] Boris, J.P., K. Obenschain, G. Patnaik, and T.R. Young, Jr., 2002. CT-Analyst: Portable Tool for Dispersion Prediction with Zero Delay and High Fidelity. In Proceedings of Fourth George Mason University Transport and Dispersion Modeling Workshop, George Mason University, Fairfax VA. July 11-12.

[58] Reshetin, V.P., Regens, J.L., 2003. Simulation Modeling of Anthrax Spore Dispersion in a Bioterrorism Incident. Risk Analysis: An International Journal, Dec2003, Vol. 23 Issue 6, p1135-1145.

[59] Y. Li, S. Duan, I. T. S. Yu, T. W. Wong, 2005. Multi-zone modeling of probable SARS virus transmission by airflow between flats in Block E, Amoy Gardens. Indoor Air 15 (2), 96–111.

[60] Weidong Z., and Miller, C.T., Digiano, F.A., 2004. Bacterial Regrowth Model for Water Distribution Systems Incorporating Alternating Split-Operator Solution Technique. Journal of Environmental Engineering, Sept., Vol. 130 Issue 9, p932-941.

[61] Semenchenko, V., Razlutskij, V., Feniova, I., and Aibulatov, D., 2007. Biotic relations affecting species structure in zooplankton communities. Hydrobiologia, March, Vol. 579 Issue 1, p219-231.

[62] Fukami, T., 2005. Integrating internal and external dispersal in metacommunity assembly: preliminary theoretical analyses. Ecological Research, November, Vol. 20 Issue 6, p623-631.

[63] Higgins, S.I., Richardson, D.M., and Cowling, R.M., 2001. Validation of a spatial simulation model of a spreading alien plant population. By: Journal of Applied Ecology, Jun2001, Vol. 38 Issue 3, p571-584.

[64] Wainer, G., 2006. Applying Cell-DEVS Methodology for Modeling the Environment, SIMULATION, vol. 82, No. 10, pp. 635 - 660.

[65] Coies, S., and Simiu, E., 2003. Estimating Uncertainty in the Extreme Value Analysis of Data Generated by a Hurricane Simulation Model. Journal of Engineering Mechanics, November, Vol. 129 Issue 11, p1288-1294.

[66] Rosmond, T.E., 2000. A scalable version of the Navy Operational Global Atmospheric Prediction System spectral forecast model. Scientific Programming, Vol. 8 Issue 1, p31-38.

[67] Shen, J., Parker, A., and Riverson, J., 2005. A new approach for a Windows-based watershed modeling system based on a database-supporting architecture. Environmental Modelling & Software, September, Vol. 20 Issue 9, p1127-1138.

[68] Lam, D., Leon, L., Hamilton, S., Crookshank, N., Bonin, D., and Swayne, D. 2004. Multi-model integration in a decision support system: a technical user interface approach for watershed and lake management scenarios. Environmental Modelling & Software, March, Vol. 19 Issue 3, p317-324.

[69] Niewiadomska-Szynkiewicz, E., 2004. Computer Simulation of Flood Operation in Multireservoir Systems. SIMULATION, 2 2004; vol. 80: pp. 101 - 116.

[70] Jack, L. B., Cheng, C., and Lu, W. H., 2006. Numerical simulation of pressure and airflow response of building drainage ventilation systems. Building Services Engineering Research & Technology, June, Vol. 27 Issue 2, p141-152.

[71] Sohn, M.D., Apte, M.G., Sextro, R.G., and Lai, A.C.K., 2007. Predicting size-resolved particle behavior in multizone buildings. Atmospheric Environment, March, Vol. 41 Issue 7, p1473-1482.

[72] Chang, T.-J., Kao, H.-M., and Hsieh, Y.-F., 2007. Numerical Study of the Effect of Ventilation Pattern on Coarse, Fine, and Very Fine Particulate Matter Removal in Partitioned Indoor Environment. Journal of the Air & Waste Management Association, Feb., Vol. 57 Issue 2, p179-189.

[73] Wang, D., Berry, M.W., Carr, E.A., and Gross, L.J., 2006. A Parallel Fish Landscape Model for Ecosystem Modeling, SIMULATION, vol. 82, Number 7, pp. 451 - 465.

[74] Sasai, Y., Ishida, A., Sasaki, H., Kawahara, S., Uehara, H., and Yamanaka, Y., 2006. A Global Eddy-Resolving Coupled Physical-Biological Model: Physical Influences on a Marine Ecosystem in the North Pacific. SIMULATION, vol. 82, No. 7, pp. 467 - 474.

[75] Hill, D., Coquillard, P. , Aussem, A., de Vaugelas, J., Thibaut, T., and Meinesz, A., 2001. Modeling the Ultimate Seaweed Expansion. SIMULATION, vol. 76, No. 2, pp. 126 - 134.

[76] Bulitko, V., and Wilkins, D.C., 2003. Qualitative simulation of temporal concurrent processes using Time Interval Petri Nets. Artificial Intelligence, Volume 144, Issues 1-2, pp. 95-124.

[77] Tang, L., Chen, C., Huang, H., and Lin, K., 2006. Research on HLA-based Forest Fire Fighting Simulation System. 9th AGILE Conference on Geographic Information Science, Visegrád, Hungary, pp.366-373.

[78] Batty, M., Desyllas, J., Duxbury, E., 2003. Safety in numbers? Modelling crowds and designing control for the Notting Hill carnival. Urban Studies. July, Vol. 40, Iss. 8, pp. 1573-1590.

[79] van Laere, J ., de Vreede, G.J., Sol, H.G., 2006. A social simulation-game to explore future co-ordination in knowledge networks at the Amsterdam Police Force. Production Planning & Control. September. Vol. 17, Iss. 6, pp. 558-568.

[80] Lee, E.K., Maheshwary, S., Mason, J., and Glisson, W., 2006. Large-Scale Dispensing for Emergency Response to Bioterrorism and Infectious-Disease Outbreak. Interfaces, Nov/Dec, Vol. 36 Issue 6, p591-607.

[81] Miller, G., Randolph, S., and Patterson, J.E., 2006. Responding to Bioterrorist Smallpox in San Antonio. Interfaces, Nov/Dec, Vol. 36 Issue 6, p580-590.

[82] Duguay, C. and Chetouane, F., 2007. Modeling and Improving Emergency Department Systems using Discrete Event Simulation. SIMULATION, Vol. 83 No. 4, p. 311 - 320.

[83] Whitworth, M.H., 2006. Designing the Response to an Anthrax Attack. Interfaces, Nov/Dec, Vol. 36 Issue 6, p562-568.

[84] Kanno, T., Morimoto, Y., and Furuta, K., 2006. A distributed multi-agent simulation system for the assessment of disaster management systems. International Journal of Risk Assessment & Management, Vol. 6 Issue 4/5/6, pp. 528-544.

[85] Comfort, L.K., Ko,K., and Zagorecki, A., 2004. Coordination in Rapidly Evolving Disaster Response Systems: The Role of Information. American Behavioral Scientist, vol. 48, No. 3: pp. 295 - 313.

[86] Nasim Uddin, P.E., and Engi, D., 2002. Disaster Management System for Southwestern Indiana. Natural Hazards Rev., Volume 3, Issue 1, pp. 19-30.

[87] Raczynski, S., 2004. Simulation of The Dynamic Interactions Between Terror and Anti-Terror Organizational Structures, Journal of Artificial Societies and Social Simulation vol. 7, no. 2, article 8.

[88] Tsvetovat, M. & Carley, K., 2005. Structural Knowledge and Success of Anti-Terrorist Activity: The Downside of Structural Equivalence. Journal of Social Structure, Vol. 6, No. 2, Available on-line via: http://www.cmu.edu/joss/content/articles/volume6/TsvetovatCarley/index.html, last accessed on May 20, 2007.

[89] Corman, S.R., 2006. Using activity focus networks to pressure terrorist organizations. Computational and Mathematical Organization Theory. April, Vol. 12, Iss. 1, p. 35-49.

[90] Min, H.-S.J., Beyeler, W., Brown, T., Son, Y.J., and Jones, A.T., 2007. Toward modeling and simulation of critical national infrastructure interdependencies. IIE Transactions, January, Vol. 39 Issue 1, p57-71.

[91] Conrad, S.H., LeClaire, R.J., O'Reilly, G.P., and Uzunalioglu, H., 2006. Critical national infrastructure reliability modeling and analysis. Bell Labs Technical Journal, Fall, Vol. 11 Issue 3, p57-71.

[92] Wolf, E., 2003. Using Agent-Based Distillations to Explore Logistics Support to Urban, Humanitarian Assistance/Disaster Relief Operations, Naval Postgraduate School Monterey CA, USA.

[93] Stephen, R.T., Anderson, M.A., and Lauren, M.K., MANA: Map Aware Non-uniform Automata Version 2.0 User's Manual, New Zealand Defence Technology Agency, July 2002.

[94] van der Gaag, M.A., Vos, F., Saatkamp, H.W., van Boven, M., van Beek, P., and Huirne, R.B.M., 2004. A state-transition simulation model for the spread of Salmonella in the pork supply chain. European Journal of Operational Research, Aug2004, Vol. 156 Issue 3, p782-798.

[95] Beamon, B.M., and Kotleba, S.A., 2006. Inventory management support systems for emergency humanitarian relief operations in South Sudan, The International Journal of Logistics Management, Vol. 17, Issue: 2, pp. 187 - 212.

[96] Baran, M. E., and El-Markabi, I. M., 2007. A Multiagent-Based Dispatching Scheme for Distributed Generators for Voltage Support on Distribution Feeders. IEEE Transactions on Power Systems, Volume 22, Issue 1, pp. 52 - 59.

[97] Baxevanos, L.S., and Labridis, D.P., 2007. Implementing Multiagent Systems Technology for Power Distribution Network Control and Protection Management. IEEE Transactions on Power Delivery, January, Vol. 22 Issue 1, p433-443.

[98] Esmaeili, S., and Kouhsari, S.M., 2007. A distributed simulation based approach for detailed and decentralized power system transient stability analysis. Electric Power Systems Research, April, Vol. 77 Issue 5/6, pp. 673-684.

[99] Athanasiadis, I.N., Mentes, A.K., Mitkas, P.A., and Mylopoulos, Y.A., 2005. A Hybrid Agent-Based Model for Estimating Residential Water Demand. SIMULATION, vol. 81, No. 3, pp. 175 - 187.

[100] López-Paredes, A., Saurí, D., and GalánUrban, J.M., 2005. Water Management with Artificial Societies of Agents: The FIRMABAR Simulator. SIMULATION, vol. 81, No. 3, pp. 189 - 199.

[101] Qiao, J., Jeong, D., Lawley, M., Richard, J.-P.P., Abraham, D.M., and Yih, Y., 2007. Allocating security resources to a water supply network. IIE Transactions, January, Vol. 39 Issue 1, p95-109.

[102] Lee, J.-K., Lim, Y.-H., and Chi, S.-D., 2004. Hierarchical Modeling and Simulation Environment for Intelligent Transportation Systems. SIMULATION, vol. 80, No. 2, pp. 61 - 76.

[103] Sahraoui, A.-E.-K., and Jayakrishnan, R., 2005. Microscopic-Macroscopic Models Systems Integration: A Simulation Case Study for ATMIS. SIMULATION, vol. 81, issue 5, pp. 353 - 363.

[104] Sisiopiku, V. P., 2007. Application of Traffic Simulation Modeling for Improved Emergency Preparedness Planning, Journal of Urban Planning & Development, Mar2007, Vol. 133, Issue 1, p51-60

[105] Arseni, P., Boggia, G., and Camarda,P., 2002. Modeling Telecommunication Infrastructures Integrating Wideband Wireless and Wired Networks. SIMULATION, vol. 78, No. 3, pp. 173 - 184.

[106] Joshi, M., Mansata, A., Talauliker, S., and Beard, C., 2005. Design and analysis of multi-level active queue management mechanisms for emergency traffic. Computer Communications, February, Vol. 28 Issue 2, p162-173.

[107] Liljenstam, M., Liu, J., Nicol, D.M., Yuan, Y., Yan, G., and Grier, C., 2006. RINSE: The Real-Time Immersive Network Simulation Environment for Network Security Exercises (Extended Version). SIMULATION, vol. 82, No. 1, pp. 43 - 59.

[108] McGregor, P., Kaczmarek, R., Mosley, V., Dease, D., and Adams, P., 2006. National Security/Emergency Preparedness and the Next-Generation Network. IEEE Communications Magazine, May, Vol. 44 Issue 5, p133-143.

[109] Chen, S., Tang, Y., Du, W., 2007. Stateful DDoS attacks and targeted filtering. Journal of Network & Computer Applications, August, Vol. 30 Issue 3, p823-840.

[110] Polsani, P.R., 2003, "Use and abuse of reusable learning objects," Journal of Digital Information, Volume 3 Issue 4, Article No. 164, 2003-02-19.

[111] Breakaway Games, 2007. Incident Commander: A Crisis Training Simulation. Available on line via: http://www.incidentcommander.net/, last accessed on May 26, 2007.

[112] CNET Networks, Firefighter Command: Raging Inferno. Available on-line via: http://www.gamespot.com/pc/strategy/firecaptainbayareainferno/index.html, last accessed on May 26, 2007.

[113] Christopher, A., 2005. Games Tackle Disaster Training. Wired. Available on-line via: http://www.wired.com/science/discoveries/news/2005/12/69580, last accessed on May 26, 2007.

[114] Jenvald, J., and Morin, M., 2004. Simulation-Supported Live Training for Emergency Response in Hazardous Environments, Simulation & Gaming, 9 2004; vol. 35: pp. 363 - 377.

[115] Mendonça, D., Beroggi, G.E.G., van Gent, D., Wallace, W.A., 2006. Designing gaming simulations for the assessment of group decision support systems in emergency response. Safety Science, Vol. 44 Issue 6, July, p523-535.

[116] Stolk, D., Alexandrian, D., Gros, B., and Paggio, R., 2001. Gaming and multimedia applications for environmental crisis management training. Computers in Human Behavior, Volume 17, Issues 5-6, September November, Pages 627-642.

[117] Stanfield, S., Shawver, D., Sobel, A., Prasad, M., and Tapia, L., 2000. Design and Implementation of a Virtual Reality System and Its Application to Training Medical First Responders. In PRESENCE – Teleoperators and virtual environments, Vol. 9, No. 6, pp.524-556, MIT Press, December.

[118] Félez, J., Maroto, J., Romero, G., and Cabanellas, J.M., 2007. A Full Driving Simulator of Urban Traffic including Traffic Accidents. SIMULATION, Vol. 83, No. 5, p. 415 – 431.

Sanjay Jain *is an Assistant Professor in the Department of Decision Sciences, School of Business at the George Washington University (GWU). His research is sponsored by the National Institute of Standards and Technology. Sanjay serves as an associate editor of the International Journal of Simulation and Process Modeling and also as a member of the editorial board of International Journal of Industrial Engineering. He is a senior member of the Institute of Industrial Engineers and a member of APICS - The Association for Operations Management. He received a Bachelors of Engineering from Indian Institute of Technology (IIT)-Roorkee, India, a Post Graduate Diploma from National Institute of Industrial Engineering, Mumbai, India, and a Ph.D. in Engineering Science from Rensselaer Polytechnic Institute, Troy, New York.*

***Charles R. McLean** is a computer scientist and Group Leader of the Manufacturing Simulation and Modeling Group at the National Institute of Standards and Technology. He has managed research programs in manufacturing simulation, engineering tool integration, product data standards, and manufacturing automation at NIST since 1982. He has authored more than 50 technical papers on topics in these areas. He is on the Executive Board of the Winter Simulation Conference and the Editorial Board of the International Journal of Production, Planning, and Control. He is formerly the Vice Chairman of the International Federation of Information Processing (IFIP) Working Group on Production Management Systems (WG 5.7). He holds an M.S. in Information Engineering from University of Illinois at Chicago and a B.A. from Cornell University.*